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RESEARCH MEMORANDUM

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INVESTIGATION OF LITHIUM HYDRIDE AND MAGNESIUM

AS HIGH-TEMPERATURE INTERNAL COOLANTS

WITH SEVERAL SKIN MATERIALS

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
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SUMMARY

Hemispherical nose shapes of titanium, stainless steel coated with aluminum oxide, and uncoated stainless steel were investigated with lithium hydride and magnesium as internal coolants. The models were tested in the ceramic-heated jet (laboratory model) at a Mach number of 2, a stagnation temperature of 4,000° F, and a stagnation pressure of 105 lb/sq in. abs. A marked cooling effect was noted for lithium hydride with all models tested. A slight cooling effect was noted for the models cooled with magnesium. Paraffin was used to prevent internal oxidation of the coolants, with an accompanying increase in cooling efficiency.

INTRODUCTION

Configurations showing promise of withstanding the high heat loads encountered by hypersonic missiles include blunt nose shapes utilizing the energies of dissociation of chemical compounds and the latent heats of vaporization of certain elements and compounds for internal cooling.

Two substances potentially capable of absorbing large amounts of heat are lithium hydride and magnesium. At atmospheric pressure, lithium hydride begins to decompose to hydrogen gas and lithium metal at 1,500° F. This decomposition process absorbs 6,900 Btu per pound of lithium hydride decomposed (ref. 1). Magnesium vaporizes to absorb 2,300 Btu per pound at 2,030° F.

Use of a coolant internally requires a skin material having melting or ignition temperatures, whichever is lower, somewhat higher than the working temperature of the coolant. The allowable outside skin

temperature must be sufficiently high to permit a temperature gradient through the skin that will transfer the heat imposed.

This report deals with preliminary work done at the Langley Aeronautical Laboratory to determine suitable combinations of skin materials and coolants and represents an extension of the work reported in reference 1.

MODELS AND TESTS

All models tested in this investigation were hemisphere-cylinder shells. There were eight models: three of titanium, three of uncoated 347 stainless steel, and two of 347 stainless steel coated with aluminum oxide (Al_2O_3). The Al_2O_3 coatings were flame-sprayed on the models at Langley by the Rokide process. One model of each type was uncooled, and one of each contained a measured amount of lithium hydride. One titanium model and one uncoated 347 stainless-steel model contained measured amounts of magnesium powder. Table I gives the weights and dimensions of all models and the coolant weights for the cooled models. The variation in wall thicknesses for the stainless-steel models was unintentional but was due to difficulty of machining.

A small quantity of paraffin was added to each cooled model to prevent oxidation of the coolants.

The models were tested at a stagnation temperature of $4,000°$ F, a Mach number of 2, and a stagnation pressure of 105 lb/sq in. abs in the ceramic-heated jet (laboratory model) at the Langley Aeronautical Laboratory. A description of this testing facility is given in reference 2.

The lithium hydride used was commercially pure No. 30 mesh powder, and the magnesium was commercial flash powder.

Instrumentation was accomplished with No. 30 gage chromel-alumel thermocouples peened in place at the center of the inside front wall of each model. Observations of the tests were recorded on 16-millimeter motion-picture film (color).

Figure 1 shows the configuration of a typical cooled model and support. The model was tested in an upright position.

DISCUSSION

Titanium Models

The curves for temperature plotted against time for the three tita-
nium models are shown in figure 2. Horizontal lines in the figure indi-
cate the boiling point of magnesium and the decomposition temperature
of pure lithium hydride. All thermocouples failed at approximately
$2,300^{\circ}$ F.

The motion pictures of the tests showed that the uncooled model
started burning 0.7 second after it entered the jet. The model cooled
with magnesium started burning at 1.3 seconds, whereas the model cooled
with lithium hydride did not begin to burn until the model was in the
jet 5.6 seconds. Approximately 0.2 second was required for each model
to be completely consumed once burning was initiated. Figure 3 shows
all three models at 0.8 second, the uncooled model and the model cooled
with magnesium at 1.2 seconds, and the model cooled with lithium hydride
at 5.6 seconds.

Stainless-Steel Models (Uncoated)

Three uncoated stainless-steel models were tested, one with lithium
hydride and one with magnesium as coolants and one uncooled. The uncooled
model and the model containing lithium hydride were essentially the same
as the models reported in reference 1, with the exception that a small
amount of paraffin was added to the cooled model to prevent internal
oxidation of the coolant. Figure 4 shows the temperature-time curves
for the uncooled model and the model cooled with lithium hydride. The
large difference between the skin thickness of the magnesium-cooled
model and that of the uncooled model made comparison difficult (see
table I); therefore, figure 5 shows the temperature-time curve for the
magnesium-cooled model and the estimated curve for an uncooled model
of the same skin thickness. Figures 4 and 5 show that the lithium
hydride and, to a lesser extent, the magnesium offer significant
cooling when used with a stainless-steel skin. However, the cooling
afforded by the magnesium is apparently due to its heat capacity, and
not to the latent heat of vaporization, since the model did not reach
the boiling point of magnesium until just before it melted.

The motion pictures show that the uncooled model began to glow at
1.8 seconds. Melting started at 4.0 seconds with the molten metal
burning vigorously. At 5.1 seconds, the skin of the model was melted
through at the nose. The melting point of 347 stainless steel is
approximately $2,600^{\circ}$ F.

The model cooled with magnesium began melting at 3.8 seconds and was melted through at 4.9 seconds. The model cooled with lithium hydride began melting 10.7 seconds from the time it entered the jet. At 12.8 seconds melting stopped after a noticeable amount of skin was lost. From 12.8 to 14.4 seconds, a reddish flame was observed around the front of the model, which could have been caused by the coolant coming through a small opening in the skin. No deterioration of the model was noted during this time. At 14.4 seconds, melting started again, and the model was immediately consumed. This constitutes a considerable improvement over the 7.8 seconds reported in reference 1 for destruction of a model that was similar but that did not contain paraffin to prevent oxidation of the coolant.

Stainless-Steel Models Coated With Aluminum Oxide

Figure 6 gives the curves for temperature plotted against time for the two stainless-steel models coated with aluminum oxide (Al_2O_3). While a cooling effect may be observed toward the end of the run for the model containing the lithium hydride, the results are not so conclusive as for the titanium and uncoated stainless-steel models. Figure 5 shows that the cooled model was at a higher temperature than the uncooled model for the first 10.5 seconds, but this is because the cooled model had a thinner wall as is shown in table I. The insulating effect of the Al_2O_3 was such that heat transfer was insufficient to begin decomposition of the lithium hydride until the run was almost completed. Neither the uncooled nor the cooled model was damaged during the jet run.

Solution Effects on the Decomposition Temperature

of Lithium Hydride

The decomposition temperature of a substance decomposing to give one or more gases may be defined as the temperature at which the combined vapor pressure of the liberated gases over (at the surface of) the substance is equal to the environmental pressure. The vapor pressure of hydrogen over pure lithium hydride is 1 atmosphere at 1,520° F (ref. 3). Therefore, if the environmental pressure is 1 atmosphere, the decomposition temperature of pure lithium hydride is 1,520° F. The decomposition temperature increases as the lithium hydride decomposes and becomes a solution of lithium hydride and lithium.

The temperature-time curves for the titanium model cooled with lithium hydride (fig. 2) indicate that the decomposition temperature is increased to approximately 2,000° F as decomposition goes to completion.

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Effect of Lithium Hydride and Magnesium on

Temperature Measurements

The thermocouple wires used to measure temperatures of the models were passed through the vent hole shown in figure 1 and were peened to the inside front walls of the models. Of necessity, the wires were bare for a small distance before they reached the model walls. As a result, the presence of a conductor around the thermocouple wires would short the wires and cause them to measure the temperature of the conductor instead of the wall.

The magnesium powder shorted the wires as soon as it melted. However, the thermal conductivity of the magnesium is such that the liquid metal is at approximately the same temperature as the inside wall.

Lithium hydride is a conductor of electricity above its melting point (ref. 3). It is a fair conductor of heat, with conductivity improving as decomposition proceeds and a higher percentage of lithium metal forms in the lithium hydride. Initially, the thermocouples in the models cooled with lithium hydride measure the inside wall temperature, but after the lithium hydride melts, the thermocouples measure the coolant temperature, as evidenced by the hump in the curves for the cooled models (figs. 2, 4, and 6). The temperature of the inside wall is somewhat higher than the temperature of the lithium hydride because of the low thermal conductivity of the solution. The thermal conductivity of the solution of lithium hydride and lithium metal is not known; therefore, no accurate estimate can be made of the probable wall temperature. However, it is probable that the actual wall temperature is at least as high as the highest temperature measured before the thermocouples are shorted.

Efficiency of Models Cooled With Lithium Hydride

The heat-transfer coefficients for the sides of models in the ceramic-heated jet are not well known because of the interference between the bow shock wave and the jet boundaries and reflected waves from these interferences. Therefore, an accurate calculation of the efficiency of the coolant cannot be made from temperature data. However, a minimum efficiency can be calculated from known heat-transfer coefficients for the stagnation region.

Reference 4 gives stagnation-region heat-transfer coefficients for models in the jet. Using these coefficients, the total heat input to the hemispherical part of the titanium model cooled with lithium hydride during the time of cooling (0.5 to 5.5 sec) is calculated to be 4 Btu.

The 0.0012 pound of lithium hydride in the model can absorb 8 Btu on complete decomposition. Therefore, the efficiency is at least 50 percent. No attempt is made to calculate heat inputs to the stainless-steel models, because of the skin thickness and the melting and burning of the uncoated model which would invalidate stagnation-region heat-transfer coefficients.

The efficiency of the lithium hydride in the titanium model is at least twice that reported for lithium hydride in stainless steel (ref. 1). This is attributed to the higher operating temperature allowed by the titanium and to the prevention of internal oxidation by the addition of paraffin.

CONCLUDING REMARKS

A preliminary investigation of lithium hydride and magnesium as coolants with models of titanium, stainless steel coated with aluminum oxide, and uncoated stainless steel leads to the following conclusions for the test conditions and model wall thicknesses:

1. Lithium hydride offers significant cooling for titanium, stainless steel, or stainless steel coated with aluminum oxide.

2. Magnesium shows a slight cooling effect for titanium, and some cooling for stainless steel as compared with the estimated temperature-time curve for an uncooled model of the same skin thickness.

3. For missile skins using internal coolants, it is important that the skin be as thin as possible and have high thermal conductivity.

4. A considerable increase in efficiency of lithium hydride as a coolant is afforded by preventing oxidation of the coolant inside the models and by use of a skin material having a high allowable temperature.

Langley Aeronautical Laboratory,
    National Advisory Committee for Aeronautics,
        Langley Field, Va., Feb. 3, 1958.

APPENDIX

THE VARIATION OF THE DECOMPOSITION TEMPERATURE OF

LITHIUM HYDRIDE AS DECOMPOSITION

GOES TO COMPLETION

The decomposition of lithium hydride is an equilibrium process. That is, there are two reactions: one, the dissociation of lithium hydride molecules, and the other, the reaction of hydrogen and lithium to form lithium hydride. Expressed symbolically these reactions are
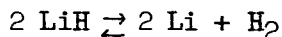
$$2 \text{ LiH} \rightleftarrows 2 \text{ Li} + \text{H}_2$$

The forward reaction $(2 \text{ LiH} \rightarrow 2 \text{ Li} + \text{H}_2)$ is proportional to the concentration of lithium hydride molecules on the surface of the lithium hydride. The reverse reaction $(2 \text{ Li} + \text{H}_2 \rightarrow 2 \text{ LiH})$ is proportional to the square of the concentration of lithium atoms on the surface and to the vapor pressure of hydrogen over the surface. An increase in temperature increases the rates of both reactions. However, the increase in the forward reaction is much greater than the increase in the reverse reaction, so that the overall effect of an increase in temperature is to shift the equilibrium in the forward direction.

For pure lithium hydride, the concentration of lithium hydride molecules on the surface is 100 percent, whereas there is no concentration of lithium atoms. However, lithium hydride does not remain pure, since decomposition will proceed until the vapor pressure of the released hydrogen and the concentration of lithium atoms on the surface become sufficiently high to bring about equilibrium between the two reactions. In a vented container, this decomposition will continue indefinitely, since the hydrogen will escape the vicinity of the surface and will not build up a vapor pressure sufficient to maintain equilibrium. However, if the equilibrium pressure is less than ambient pressure, this decomposition proceeds slowly, since a hydrogen pressure close to equilibrium pressure will be maintained immediately adjacent to the surface. When the equilibrium pressure rises because of increased temperature above ambient pressure, removal of hydrogen takes place by flow instead of diffusion, and it becomes impossible to maintain local hydrogen pressure close to equilibrium. Therefore, the forward reaction proceeds much more rapidly than the reverse.

But as the decomposition proceeds, this brings about an increase in the concentration of lithium atoms on the surface with an accompanying

acceleration of the reverse reaction, a lowering of the equilibrium
hydrogen pressure, and, in overall effect, an increase in the tempera-
ture necessary to keep the equilibrium temperature above ambient.

REFERENCES

1. Modisette, Jerry L.: Preliminary Investigation of Lithium Hydride as a High-Temperature Internal Coolant. NACA RM L57F12a, 1957.

2. Purser, Paul E., and Hopko, Russell N.: Exploratory Materials and Missile-Nose-Shape Tests in a 4,000° F Supersonic Air Jet. NACA RM L56J09, 1956.

3. Gibb, Thomas R. P., Jr., and Messer, C. E.: A Survey Report on Lithium Hydride. A.E.C. Rep. No. NYO-3957, Lithium Corp. of America, Inc. (Minneapolis, Minn.).

4. Fields, E. M., Hopko, Russell N., Swain, Robert L., and Trout, Otto F., Jr.: Behavior of Some Materials and Shapes in Supersonic Free Jets at Stagnation Temperatures Up to 4,210° F, and Descriptions of the Jets. NACA RM L57K26, 1958.

TABLE I

DIMENSIONS AND WEIGHTS OF MODELS AND COOLANTS

Model	Material	Diameter, in.	Wall thickness, in.	Coolant	Coolant weight, lb	Model weight, lb
1	Titanium	1/2	0.029	----------	------	0.0089
2	Titanium	1/2	0.029	Lithium hydride	0.0012	0.0091
3	Titanium	1/2	0.029	Magnesium	0.0020	0.0090
4	Stainless steel	5/8	0.19	----------	------	0.044
5	Stainless steel	5/8	0.082	Lithium hydride	0.0016	0.042
6	Stainless steel	5/8	0.047	Magnesium	0.0033	0.040
7	Stainless steel coated with aluminum oxide	5/8	$0.121 + 0.01\ Al_2O_3$	----------	------	0.046
8	Stainless steel coated with aluminum oxide	5/8	$0.081 + 0.01\ Al_2O_3$	Lithium hydride	0.0014	0.044

Vent Hole
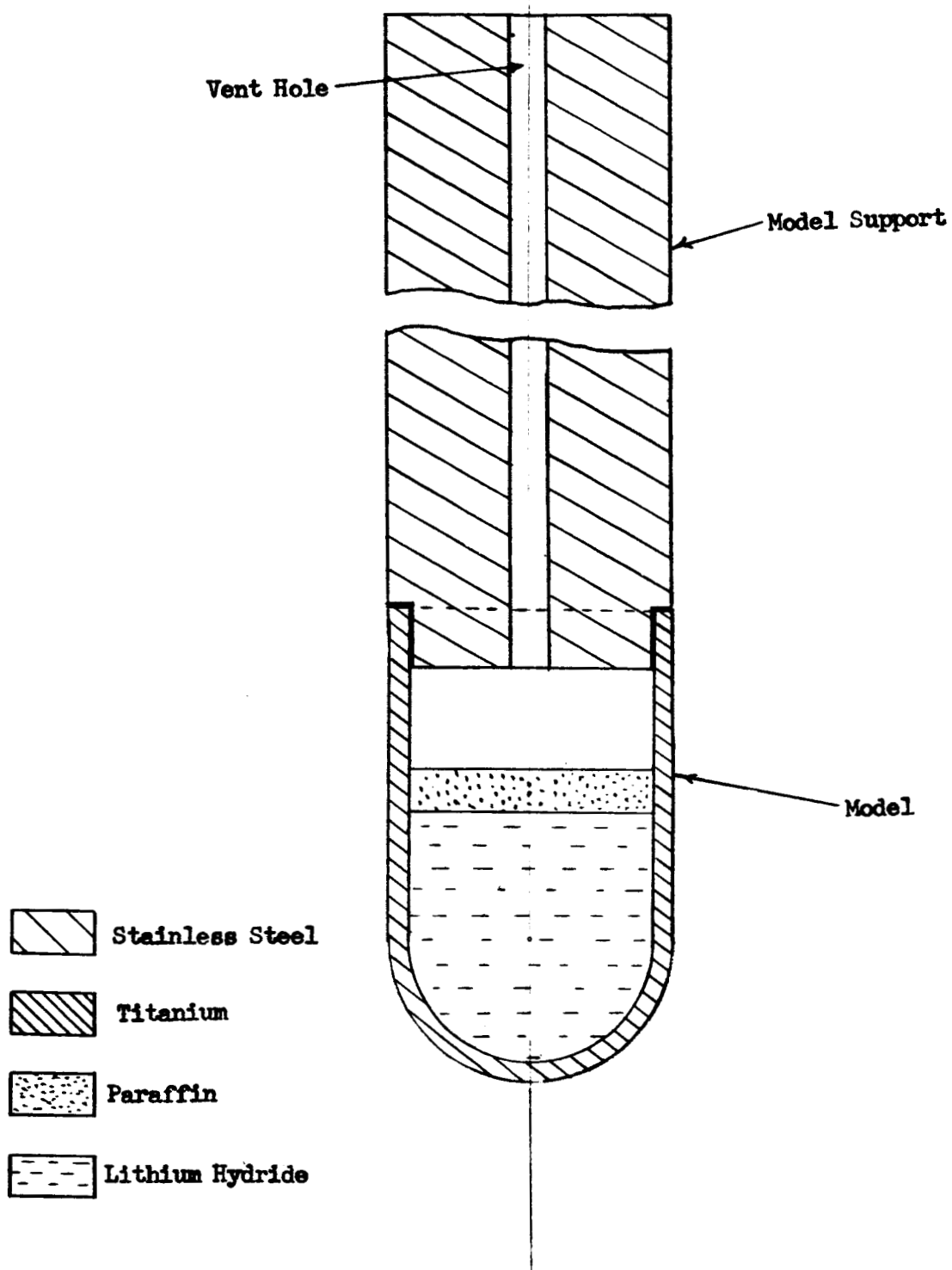
Model Support

Model

Stainless Steel

Titanium

Paraffin

Lithium Hydride

Figure 1.- Cross-section of model showing coolant, paraffin, and support.

Uncooled

Magnesium Cooled

LiH Cooled

Boiling Point of Mg

Decomposition Temperature of Pure LiH

Time, sec

Temperature, °F
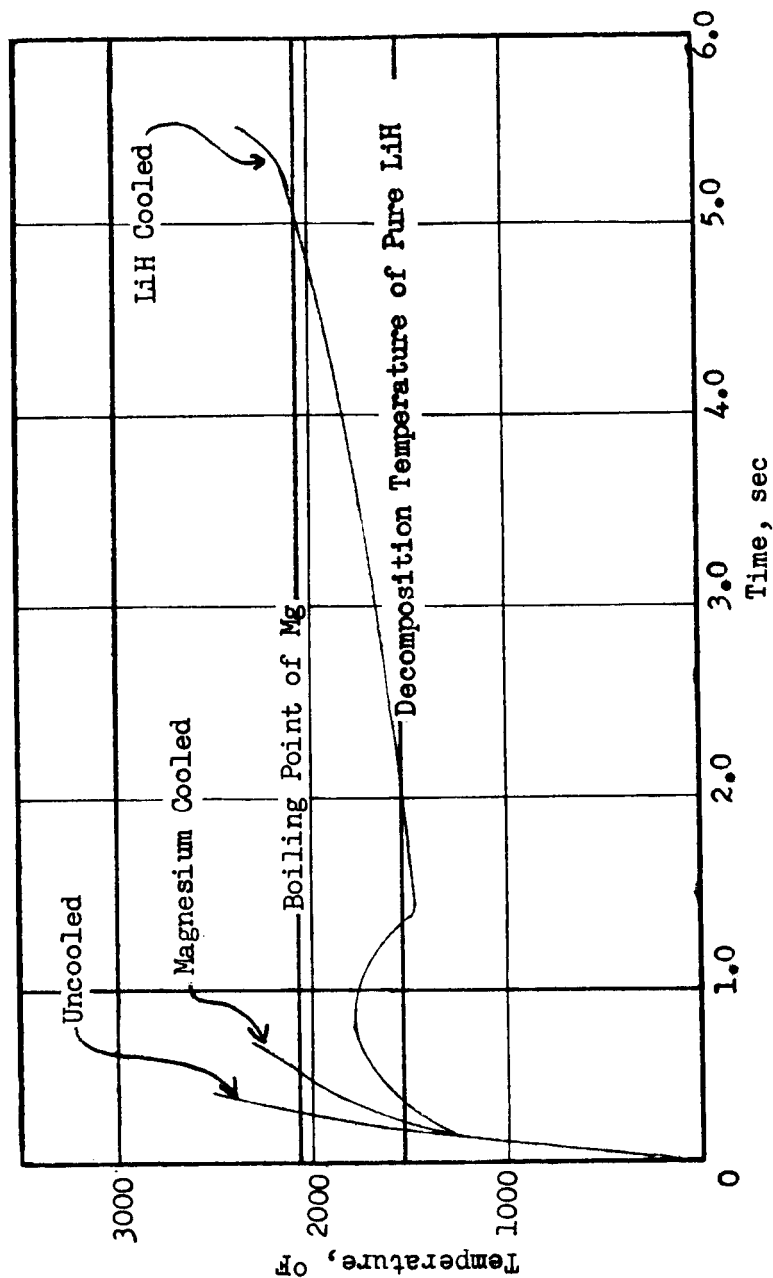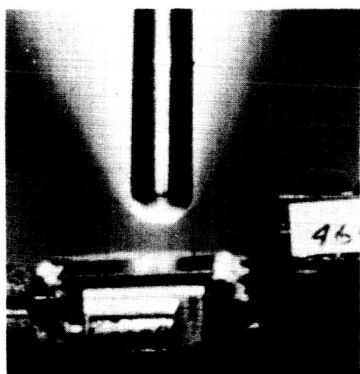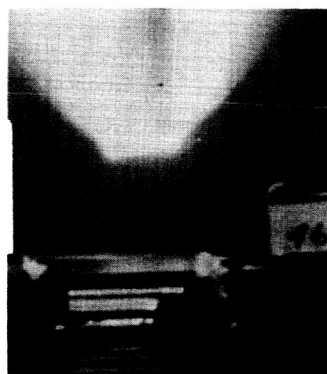
3000

2000

1000

0   1.0   2.0   3.0   4.0   5.0   6.0

Figure 2.- Temperature plotted against time for titanium models cooled with lithium hydride and magnesium.
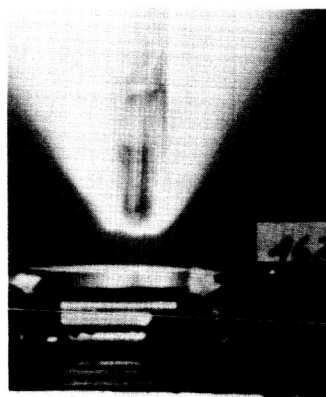
0.8 sec   1.2 sec
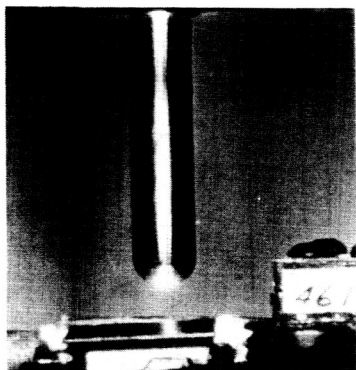
Uncooled model

0.8 sec   1.2 sec

Model cooled with magnesium

0.8 sec   5.6 sec

Model cooled with lithium hydride

Figure 3.- Titanium models.   L-58-123

Figure 4.- Temperature plotted against time for stainless-steel model cooled with lithium hydride.

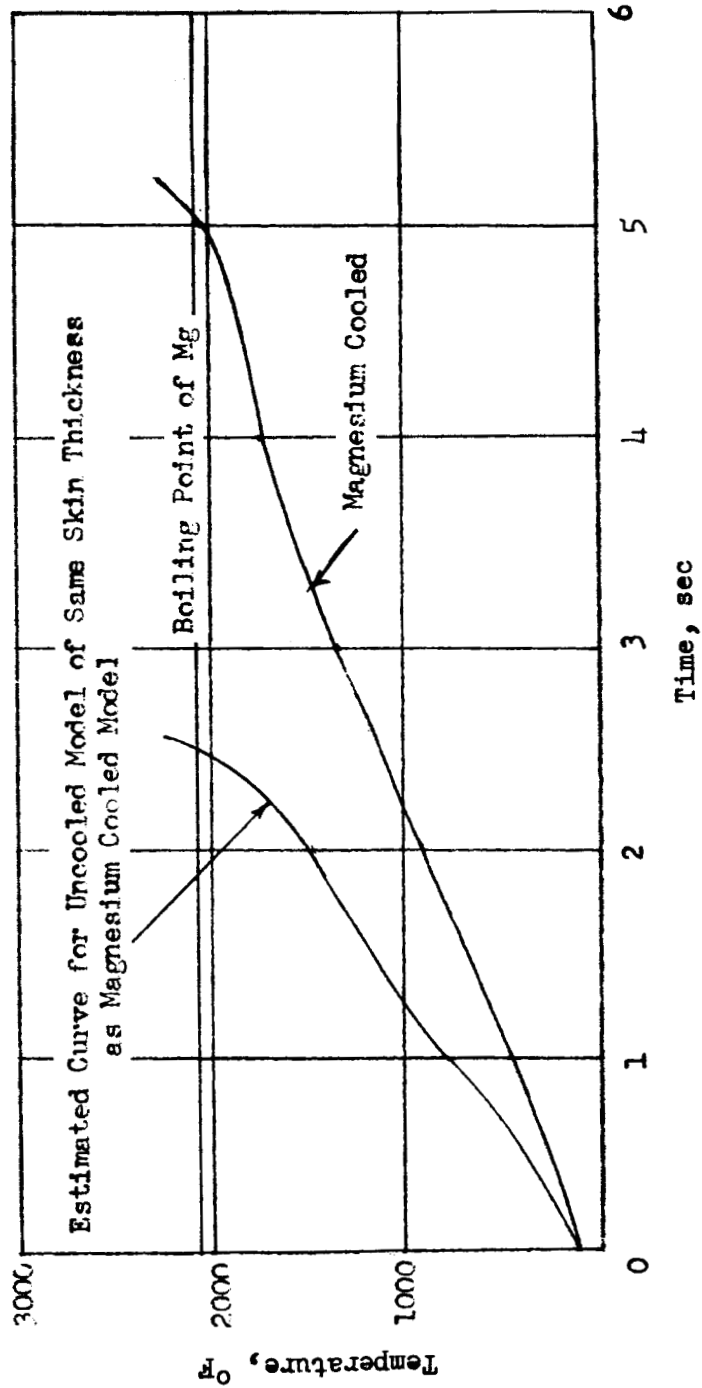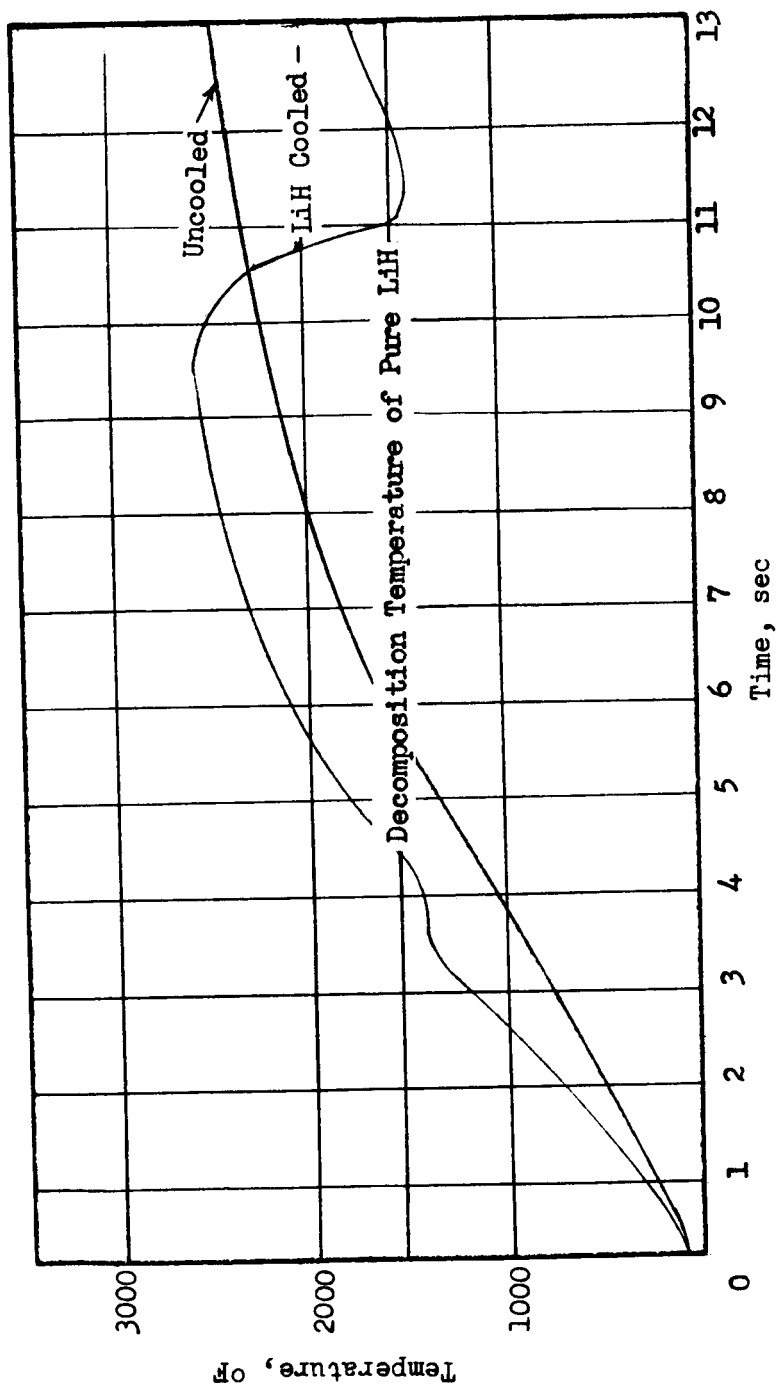Figure 5.- Temperature plotted against time for stainless-steel model cooled with magnesium.

Figure 6.- Temperature plotted against time for two models of stainless steel coated with aluminum oxide, one uncooled and one cooled with lithium hydride.